Conceptualizing Socioscientific Decision Making from a Review of Research in Science Education

Su-Chi Fang [1] & Ying-Shao Hsu[1] & Shu-Sheng Lin[2]

Abstract This article proposes a theoretical framework for conceptualizing socioscientific decision making, reviews current research in this area, and intends to shed some light on the instructional design for the classroom implementation of socioscientific decision making. The framework involves 3 phases: formulate the decision-making space, posit a decision-making strategy, and reflect on the decision-making process. A total of 24 articles that specifically focused on socioscientific decision making were included. They were classified into 2 groups. The first group explored students' socioscientific decision-making behavior and its relationships with their cognitive conditions. The second examined the effectiveness of the interventions, that is, task conditions. The analysis showed that most of the studies in both groups focused on phase 1 and studied 3 research themes: informal reasoning, evidence-based reasoning, and social interactions. The findings indicated the challenges phases 1 and 2 posed to students, such as prioritizing criteria and employing a suitable decision-making strategy. Two cognitive conditions, scientific knowledge and scientific epistemological beliefs, appeared to have a more direct impact on evidence-based reasoning rather than on informal reasoning. Group 2 studies designed various interventions and looked into divergent socioscientific decision-making performances across 3 phases. The framework helps conceptualize socioscientific decision making in a more structural and holistic way. The content review provides instructional insights for the socioscientific decision-making process and suggests several future research directions.

Keywords Decision making · Instructional design · Literature review · Socioscientific issues

Introduction

Accompanied by the rapid advances in science and technology, socioscientific issues are becoming more prominent in today's society. In this modern and global society, it is pivotal to prepare future citizens with the abilities not only to effectively tackle these situations at an individual level but also to take part in public debates and make fair judgments on how the authorities deal with these issues at a local or global level. In addition to fostering citizenship education, socioscientific issues are used as platforms for science learning (Sadler, Barab, & Scott, 2007). Therefore, supporting students' development of socioscientific decision-making competence has become an essential component in scientific literacy, and it is acknowledged as one of the important learning goals of science education (Driver, Leach, Millar, & Scott, 1996; Eggert & Bogeholz, 2010; National Research Council, 1996).

Socioscientific issues present contentious issues of up-to-date science and technology that are associated with social, scientific, political, economic, and ethical dimensions. Although the root of socioscientific issues is science, dealing with these issues cannot simply rely on scientific considerations (Eggert, Ostermeyer, Hasselhorn, & Bogeholz, 2013). There are no perfect or definitive solutions to socioscientific issues. Multiple solutions are possible, and each has its advantages and disadvantages (Sadler, 2009; Zohar & Nemet, 2002). The complex nature of socioscientific issues entails the challenges students face when making socioscientific decisions. They need to contemplate the issue from multiple dimensions, search for relevant information, engage in argumentation, apply reasoning skills, and integrate diverse perspectives into the development of their decision-making strategies. To be able to make informed socioscientific decisions is also closely related to the abilities to perform informal reasoning, that is, to consider and compare the pros and cons of different options and to posit a decision-making strategy to reach the final decision. Moreover, it is important to understand that dealing with socioscientific issues is an ongoing inquiry. One has to exhibit skepticism when encountering potentially biased information (Sadler et al., 2007). All of these socioscientific decision-making activities impose high processing demands on students (Eggert et al., 2013). Therefore, in order to successfully support students' learning of socioscientific decision making, it is a prerequisite to provide a well-designed curriculum, appropriate teaching and learning materials, and thorough instruction.

In the past decades, a growing number of studies in science education have explored relevant issues in the implementation of socioscientific issues in science classrooms. The research findings showed that socioscientific issues served as a productive platform for boosting students' interest and motivation, fostering conceptual scientific knowledge, and developing higher-order thinking skills, such as argumentation, critical thinking, problem solving, and informal reasoning (e.g. Grace, 2009; Sadler, 2009; Zohar & Nemet, 2002). The studies either delved into students' performances during the activities before making a decision or examined their ability to make a decision with a rational method; however, relatively little research has attended to *socioscientific decision making* as an integral process. To strengthen the knowledge base of socioscientific decision making, this paper proposes a theoretical framework for conceptualizing socioscientific decision making in science education, critically reviews the current knowledge in the research field, and intends to shed some light on the instructional design for enhancing students' competence in socioscientific decision making. Specifically, this review focused on three research questions:

1. What are the relationships between students' cognitive conditions and socioscientific decision making?
2. In previous research, what types of instructional interventions were designed and how did they influence students' socioscientific decision making?
3. How does the review of research inform the instructional design of socioscientific decision making?

The Theoretical Framework for this Study

In this section, the dual-process theories were first employed to describe the nature of socioscientific decision-making behavior, that is, the operations of implicit (intuitive) and explicit (analytical) cognitive systems. Following that, several models of the decision-making process suggested to promote explicit socioscientific decision making were reviewed. By integrating and incorporating these decision-making models, we propose a socioscientific decision-making framework for analyzing the relevant literature and providing insights into the teaching and learning of socioscientific decision making.

The Nature of Socioscientific Decision-Making Behavior

Informal reasoning is one critical thinking skill when dealing with socioscientific issues. In contrast to formal reasoning (scientific reasoning) that involves the use of mathematical and logic rules to solve well-defined problems, informal reasoning in socioscientific decision making requires learners to construct and evaluate arguments in the contexts of ill-structured problems (Sadler, 2004). The dual-process theories proposed in the field of psychology were adopted to explain the possible mechanism behind learners' socioscientific decision-making behavior (Böttcher & Meisert, 2013; Wu & Tsai, 2007; Wu & Tsai, 2011). According to the dual-process theories (Hogarth, 2005), human decision making involves operations of the two different cognitive systems: an intuitive (tacit or implicit) system and an analytical (deliberate or explicit) system. The usage of an intuitive system is unconscious, subject to bias, and easily influenced by emotions connected to previous experiences. On the other hand, the operation of an analytical system is conscious and involves logical and abstract thinking. When a learner encounters an ill-structured problem (such as socioscientific issues), he/she may first retrieve relevant information from previous experiences and employ the intuitive system to form a preliminary mental model of the situation. It is highly likely that an intuitive decision is subsequently made. Nevertheless, the learner can also use an analytical system to perform logical thinking, revise the initial mental model, and then make an informed decision (Böttcher & Meisert, 2013; Wu & Tsai, 2007; Wu & Tsai, 2011). In other words, the intuitive system is the default operation. One would call upon the analytical system when the current situation demands complete examination of all dimensions of a scenario. To cultivate students' socioscientific decision-making competence thus means not only recognizing the nature of human decision-making behavior but also integrating intuitive processes into the research (Böttcher & Meisert, 2013). More specifically, although intuitions may dominate a learner's decision making, he/she can be prompted to develop the ability to explicitly reflect on the intuitive decision and adjust it through proper educational interventions.

The Models of Socioscientific Decision Making

To scaffold and promote students' explicit socioscientific decision making, researchers have developed models of the decision-making process. For example, Betsch and Haberstroh (2005) proposed a phase model of the process of decision making. Rather than defining decision making in a narrow sense, this model describes it as a complex process including three phases: (1) the preselectional phase, (2) the selectional phase, and (3) the postselectional phase. During the selectional phase, one needs to identify the decision problem, generate applicable behavior, and search for related information. In the selectional phase, different options are compared and appraised, and then a choice is made. The postselectional phase underscores the implementation of the selected behavior. In addition, researchers have pointed out that the feedback after the postselectional phase is important, as it is a reflection on the use of decision-making strategies, otherwise named meta-decisions (Böttcher & Meisert, 2013; Payne, Bettman, & Johnson, 1993). Svenson (1992, 1996) introduced the Bdifferentiation and consolidation theory,^ that is, an evidence-based three-phase process, to characterize people's decision-making processes. Lee and Grace (2012) elaborated on the three-phase process in the context of socioscientific decision making. The first phase involves recognizing the problem and identifying alternative options. The second phase is differentiation, during which the individual examines available options either based on his/her intuitions and former experiences or using an explicit cognitive process—weighing the pros and cons of alternatives. In the second phase, one may take new options into consideration and modify their screening criteria. The last phase, postdecision consolidation, continues the preceding differentiation tasks to ensure that the decision being made is the most suitable one.

In addition to the models by Betsch and Haberstroh (2005) and Svenson (1992, 1996), two other models were applied frequently in teaching and learning socioscientific decision making. One useful structure is introduced by Ratcliffe (1997) and is based on the normative and descriptive decision-making models (Beyth-Marom, Fischhoff, Quadrel, & Furby, 1991; Janis & Mann, 1977). The structure includes six steps: options, criteria, information, survey, choice, and review and was designed to stimulate quality group discussions (Grace, 2009; Ratcliffe, 1997). The other is the value-focused decision-making approach advocated by McDaniels, Gregory, and Fields (1999) and Acar, Turkmen, and Roychoudhury (2010). With this approach, individuals follow five steps for deliberate decision making: (1) characterizing Bwhat matters^ to stakeholders, (2) creating alternatives, (3) employing information to identify the impacts of the alternatives, (4) identifying the tradeoffs, and (5) summarizing the agreements, disagreements, and underlying reasons for different perspectives.

Reviewing these decision-making models presented in the literature, we found that although these models used different terms, similar phases or steps for making socioscientific decisions were described. However, it is worth noting that these models draw attention to explicitly breaking down and expressing the process of informal reasoning, whereas Bthe actual action to make a decision^ based on reasoning and trade-off tasks seems to be neglected. Having a holistic view of the pros and cons of the options is a prerequisite for making a decision. However, a comprehensive comparison does not necessarily lead to a well-informed deci- sion. To reach a quality decision, one needs to take all of the criteria into account and use them to examine the options in a logical and systematic way. That is to say, a good decision maker needs to adopt an appropriate decision-making strategy to make a decision. Three commonly used decision-making strategies are intro- duced in the literature: non-compensatory strategies, compensatory strategies, and a mixture of both (e.g. Böttcher & Meisert, 2013; Gresch, Hasselhorn, & Bogeholz, 2013; Papadouris, 2012). A non-compensatory strategy means that one criterion is considered at a time (cut-off). When a knockout criterion is identified, those options that fail to meet the criteria are eliminated. A compensa- tory strategy presents the notion of weighing the trade-offs. It takes all of the criteria into consideration and analyzes the strengths and weaknesses of the possible options. The third strategy combines both the compensatory and non- compensatory strategies. That is to say, unacceptable options are first excluded (non-compensatory strategy) and trade-offs are carried out for the remaining options (compensatory strategy).

A Framework for Conceptualizing Socioscientific Decision Making in Science Education

On account of the inadequacy identified in the models presented in the literature, this study proposes a socioscientific decision-making framework based on Papadouris's work (2012) that involves not only performing informal reasoning in formulating the decision space but also using a decision-making strategy to make a decision. Apart from that, we argue that it is imperative to use meta-cognition to reflect on decision-making processes (Böttcher & Meisert, 2013; Gresch & Bögeholz, 2013). Altogether, the framework characterizes three phases of decision making (see Fig. 1): formulating the decision-making space, positing a suitable decision-making strategy to make a decision, and reflecting on the decision-making process. A more detailed expression of the three phases is provided below.

When encountering a decision-making situation, one needs to first recognize the problem and formulate the decision-making space (phase 1). In doing so, the dimensions of interest in the decision-making context and some necessary information to inform arguments or justifications are explored. After understanding the situation, possible decision options might be identified. To compare these options, one needs to set criteria and contemplate the pros and cons of the options. These two steps, setting criteria and considering the pros and cons of the options, are not always performed in a particular order. Going back and forth many times between the two steps is inevitable to comprehend the situation in a more holistic manner. The second phase pertains to the selection of a suitable decision-making strategy to make a decision. As foreshadowed in the previous section, three decision-making strategies (e.g. non-compensatory strategy, compensatory strategy, and a mixture of both) are potentially useful approaches. One needs to select and carry out the strategy for making a thoughtful decision. The third phase involves the use of meta-cognition to reflect on decision-making processes. In fact, most of the decision-making models presented in the literature included the notion of meta-cognition using various terms. Betsch and Haberstroh (2005) used the *feedback* step to highlight the importance of reflection to improve the decision-making process. Similarly, both Svenson's (1992, 1996) idea of *postdecision consolidation* and Ratcliffe's (1997) *review* implied the significant role meta-cognition plays in decision making. Indeed, applying the notion of meta-cognition in the decision-making process is essential for improving students' decisions.

The decision-making framework described above not only provided a referential structure for conceptualizing decision making but also served as an analytical tool for summarizing and synthesizing the research findings. A detailed description of the use of the decision-making framework as an analytical tool will be presented in the next section.

Methods

The Search of the Review Articles

This paper is intended to review relatively current research, so searches of journal articles were set for the past 20 years, that is from 1995 to 2015. The initial database was constructed by a search of four major international journals in science education (*Journal of Research in Science Teaching*, *International Journal of Science Education, Science Education, and Research in Science Education*) using the keywords: socioscientific issues (SSIs) and decision making. A total of 139 articles were included in this initial database. The references cited by these 139 articles were scanned for covering more relevant articles that were not published in these four major journals. Four international peer-reviewed journals: *Environmental Education Research*, *Journal of Environmental Education, Journal of the Learning Science, and Learning and Instruction* were included in the second search using the same keywords, and additional five articles were found. The review database was thus expanded to a total of 144 articles. For selecting the articles that focused on decision making in socioscientific issues, the authors completed a preliminary review of all the articles excluding those that did not provide a clear definition of decision making. We presumed that if decision making was a key construct in the study, the researchers would clearly define and explain its meaning in the article. After preliminary reading and screening, we found that few studies in the review database gave a clear definition of decision making. Only 24 articles met the criteria and thus were included in the critical content review. Most of the excluded studies adopted socioscientific decision making as their research contexts; however, decision making was not deemed a key construct in their research designs. In other words, these studies did not explicitly integrate the decision-making process in their instructional design, nor did they focus on measuring or examining relevant abilities involving in decision making.

Analyzing Procedures

The analysis in the review can be divided into two parts. In the first part, we coded basic information of the selected articles such as methodology, research design, grade level of the subjects, and the domain of the socioscientific issues. This information gave an overview of the 24 articles. Since the review focused on research findings, in the second part, a thorough content analysis was conducted based on the three phases of the decision-making framework (Fig. 1). Based on the research design, these 24 articles were classified into two groups. The first group of studies (11 articles) explored the relationships between students' *cognitive conditions* such as science knowledge or views on the nature of science and their natural decision-making performances. Another group of research (13 articles) designed various instructional interventions and investigated how these different *task conditions* impacted on students' socioscientific decision-making performances. As shown in Table 1, we first classified whether or not the study used an instructional intervention. Then, the instructional interventions (group 2 studies) and the decision-making performances measured in the studies were coded

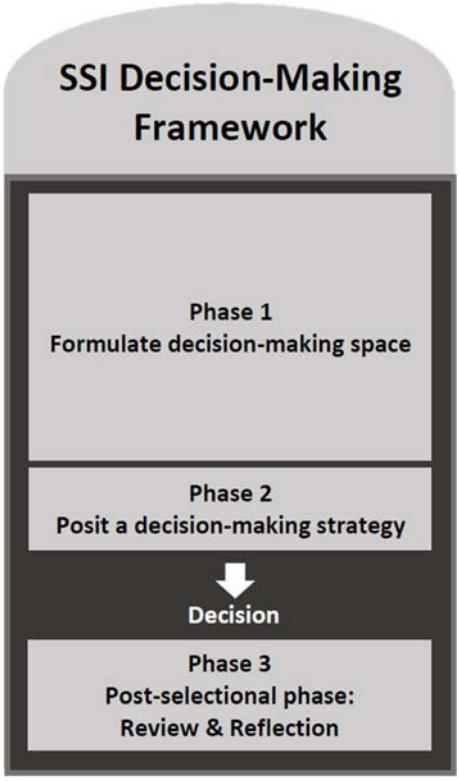

Fig. 1 Three phases in the theoretical framework of decision making

Table 1 Examples of the coding of an article with and without instructional intervention

	Paper ID 26	36
Author	Eggert, S. and S. Bogeholz (2010)	Gresch, H. and S. Bogeholz (2013)
Year	2010	2013
Title	Students' use of decision-making strategies with regard to socioscientific issues: An application of the Rasch partial credit model	Identifying non-sustainable courses of action: A prerequisite for decision-making in education for sustainable development
Journal	*Science Education* 94(2): 230–258	*Research in Science Education* 43(2): 733–754
DM intervention (1 = Yes, 0 = No)	0	1
Socioscientific task conditions (characteristics of scenarios and interventions)		
Phase 1		
Identify DM problem or dimensions of interest in the context	Scenario (covering all dimensions of sustainable development, ecological, economical, and socioeconomic aspects included)	Scenario (the interrelatedness of ecological, social, and economic facets provided to control and training groups)
Identify/generate alternative options	Scenario (these tasks represent typical DM situations with multiple possible options)	Scenario (multiple options in different scenarios)
Formulate criteria to guide the evaluation of options		
Assessing the pros and cons of options		
Phase 2		
Posit a DM strategy	Scenario (the DM processes that were presented to students represented different DM strategies)	Intervention (the training groups were taught 3 DM strategies to solve 3 DM tasks)
Phase 3		
Reflect on the DM strategy		Intervention (the 2nd training group had to do task analysis and explain why the strategy was chosen)
Review the DM process undertaken		

Student socioscientific decision-making performance

Phase 1

Table 1 (continued)

	Paper ID	
	26	36
The groups' decisions or changes in participants' decisions		
Reasoning modes or patterns		
Use of a DM structure		
Identify DM problem or dimensions of interest in the context		
Identify/generate alternative options		
Information/scientific evidence		
Criteria		
Assessing the pros and cons of options	State positive and negative aspects	
Phase 2		
Posit a DM strategy	Weighing criteria	Whether or not the students selected the DM strategies that best fit the tasks
Phase 3		
Reflect on the DM strategy	The reflection on DM strategies	Examine the quality of the students' explanations for selecting a DM strategy
Reflect on the DM process		

DM decision-making

and classified into one of three decision-making phases. Table 1 shows two examples of how each group of papers were coded.

After coding all of the 24 articles, the three authors discussed and carefully examined the coding results. At the same time, we looked for the common themes which emerged from the analysis. The themes will be explained in the BFindings^ section. This analyzing process was in line with inductive approaches for analysis of qualitative data (Corbin & Strauss, 2008). A summary of the analyzing results with respect to the themes emerged is shown in Appendix 1.

Findings

The analyzing results showed that most of the studies in both groups 1 and 2 focused on phase 1: the formulation of the decision-making space (16 articles). Three research themes emerged from the studies in phase 1: informal reasoning, evidence-based reasoning, and social interactions. Eight articles were interested in students' ability to

~~use a suitable decision-making strategy, that is, phase 2. Only three studies explicitly~~

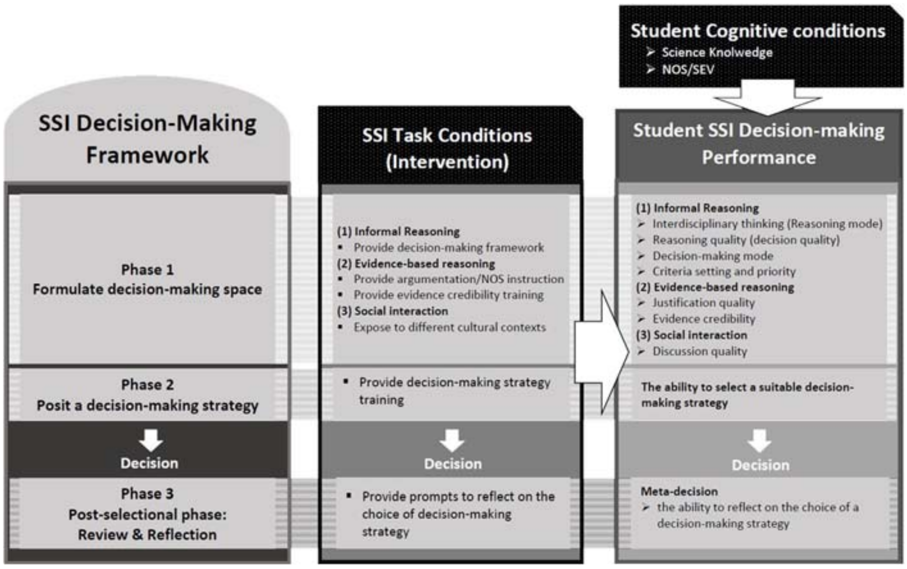

Fig. 2 A summary of the analyzing results based on the socioscientific decision-making framework

engaged students in review and reflection of decision making (phase 3). Figure 2 summarizes the themes of the two groups of the studies based on the socioscientific decision-making framework.

Group 1 Studies: Students' Cognitive Conditions and Their Socioscientific Decision-Making Performances

Eight studies in group 1 were concerned with students' phase 1 performance, including informal reasoning (interdisciplinary thinking, decision-making mode, criteria setting) and evidence-based reasoning (argumentation skills) (Sadler, 2004). Three studies looked into students' ability to select a suitable strategy to make a decision (phase 2).

Phase 1 Performances

Interdisciplinary thinking in terms of using knowledge from diverse perspectives to make decisions is one key ability to tackle a complex socioscientific problem (Liu, Lin, & Tsai, 2011). An alternative term, reasoning mode, was used to express the same idea in some studies (Wu & Tsai, 2007; Wu& Tsai, 2011). These studies revealed divergent findings about students' capability to perform interdisciplinary thinking in socioscientific settings. Wu and Tsai (2007) explored grade 10 students' informal reasoning on the issue of nuclear energy usage. Their results demonstrated that upper secondary students were able to reason the issue from various perspectives. In contrast, Liu, Lin, and Tsai (2011) found that many of the college students were unable to propose interdisciplinary ideas when facing a socioscientific issue on exotic species. For these discrepancies, researchers conjectured that what aspects students use to reason and form a decision-making space are actually affected by the nature of the socioscientific issue (Wu & Tsai, 2011). The same studies also examined students' decision-making mode, that is, to analyze whether students made decisions depending on intuitions or based on relevant evidence. They found that most of the participants were able to make evidence-based decisions. Also, those students who made decisions based on evidence were significantly more inclined to change their opinions after acquiring new information (Wu & Tsai, 2007).

Setting criteria is one important step in socioscientific decision making since the selection and the use of criteria are closely related to the evaluation of alternative options (Jimenez-Aleixandre, 2002). Uskola, Maguregi, and Jimenez- Aleixandre (2010) investigated how university students used criteria when making decisions regarding an environmental problem. The analysis of group discussions revealed that the students were able to use a great variety of criteria, both explicitly and implicitly, for justifying and substantiating their decisions. However, they rarely set priority for the criteria or considered the disadvantages of the option selected. In general, students prioritized the criteria implicitly or simply gave them equal weight. It is indeed difficult for students to weight criteria explicitly because different criteria may relate to different dimensions. Setting a priority may cause conflicts as the students need to choose one dimension over another. To enhance students' decision-making ability, this can be seen as assisting students in establishing Ba value hierarchy^
(Eggert & Bogeholz, 2010, p. 250).

Students' Cognitive Conditions and Phase 1 Performance The survey by Wu and Tsai (2007) indicated that the students' conceptual understanding regarding the issue of nuclear energy usage was not correlated with their decision-making modes. Although the students were able to reason from multiple perspectives such as social, ecological, and so on, they proposed comparatively fewer arguments from scientific or technological fields. In the same scenario, Wu and Tsai (2011) further examined the relationships between the students' cognitive structures (an indicator for student conceptual understanding) and their reasoning modes and reasoning quality. The results implied that the students with richer conceptual understandings were likely to perform high-quality reasoning. Liu et al. (2011) reported that, compared to their non-science major counterparts, science major students were inclined to draw on the science-technology perspective, and this might be due to their relatively sufficient content knowledge about science-related issues. Similarly, the research by Jho, Yoon, and Kim (2014) identified a poor correlation between knowledge base and decision making. Since students barely apply school-based scientific knowledge to socioscientific decision making (Wu & Tsai, 2007), it is likely that they do not possess sufficient abilities to connect the scientific knowledge they have learned to the socioscientific issue (Jho et al., 2014). Socioscientific issues are ill-structured problems involving multiple perspectives and interpretations (Sadler & Zeidler, 2005). Therefore, students might not prioritize scientific knowledge as the most significant factor when making a decision (Jho et al., 2014).

The influence of another cognitive condition: students' views of nature of science (NOS) or scientific epistemological beliefs (SEBs), in socioscientific decision making was emphasized in the review of the literature (Sadler, Chambers, & Zeidler, 2004; Schommer-aikins & Hutter, 2002). Bell and Lederman (2003) compared the decision-making profiles of high and low NOS groups. Their results showed that, despite their distinct views on the nature of science, no significant differences were found in the two groups' decisions, decision-influencing factors, and decision-making strategies. Two studies (Liu et al., 2011; Wu & Tsai, 2011) examined the relationships between the students' SEBs, rather than NOS, and their socioscientific decision making. According to the authors, SEBs are more likely to influence students' reasoning and decision making because they put more emphasis on the beliefs about the nature of knowing science (such as beliefs regarding the justification of scientific knowledge). Wu and Tsai (2011) pointed out that ʙjustification of scientific knowledge^ was an important predictor of reasoning quality. That is to say, the more sophisticated the learners' views on the role of experiments in science and their justifications of scientific knowledge, the better the quality of their reasoning. Moreover, students who used evidence-based or intuitive reasoning modes had similar SEB scores (Wu & Tsai, 2011). Liu et al. (2011) identified two SEV constructs, tentativeness and creativity, as significant components in socioscientific decision making. They suggested that students who believed the nature of scientific knowledge was changing and tentative were more likely to perceive the perplexity of contexts, employ multiple perspectives, and question omniscient authority.

Phase 2 Performance

The research classified into phase 2 was concerned with the ability to adopt an appropriate decision-making strategy to make final decisions. Sakschewski et al. (2014) employed a paper-and-pencil measurement to assess secondary students' decision-making competencies in the domain of energy at different grade levels. Their results indicated that the abilities of reasoning and using decision-making strategies improved with years of education. Eggert and Bogeholz (2010) measured students' decision-making approaches in varied scenarios related to sustainable development at different grade levels. They adopted the Rasch partial credit model to identify a progression from rather intuitive to more sophisticated decision making. Intuitive decision making was characterized by the use of non-compensatory decision strategies (cut-offs), that is, considering one criterion at a time, and the absence of reflection on the decision-making process. More sophisticated decision making is described by the use of com- pensatory strategies (trade-offs) and being able to weight criteria and reflect on the decision-making process. In identifying student progression in the usage of decision-making strategies, the researchers pointed out that explicitly weighing criteria itself (Eggert & Bogeholz, 2010) or in combination with the use of trade-offs posed challenges to students (Sakschewski et al., 2014).

Papadouris and Constantinou (2010) investigated sixth-grade students' approaches to comparing rival solutions in several socioscientific decision-making contexts. Their analysis identified defects and various reasoning flaws in the students' comparison strategies. Also, the students were not able to select an effective decision-making approach for different socioscientific tasks in a consistent manner. Since students tend not to be equipped with socioscientific decision-making abilities, they suggested designing a teaching sequence to facilitate students' learning.

Group 2 Studies: Task Conditions and Their Effects on Students' Socioscientific Decision-Making Performance

The second group of studies developed various instructional interventions and examined how they could improve students' socioscientific decision-making performance in the different phases.

Phase 1 Instructional Interventions

Four studies adopted a complete decision-making framework to guide students' group discussions in the decision-making process. Focusing on social interactions, these studies examined the quality of the students' discussions or investigated the impacts brought by discussions between groups from various cultural backgrounds (Grace, 2009; Grace, Lee, Asshoff, & Wallin, 2015; Lee & Grace, 2012; Ratcliffe, 1997). Ratcliffe (1997) and Grace (2009) were interested in the process of group decision making. They identified the features that facilitated high-quality discussion and decision making. Ratcliffe (1997) developed a six-step structure (options, criteria, information, survey, choice, review) for supporting students' decision making. A comparison was made between high and low achieving groups. Ratcliffe concluded that to have high-quality group decision making, individuals needed to be aware of the reasons behind the procedures for considering alternatives, be able to recognize relevant information and scientific concepts, explicitly identify important criteria, and be willing to accept others' viewpoints and have sustained motivation. Despite these favorable features being identified, the author pointed out that the students could not use relevant information cautiously, nor could they use the identified criteria systematically. Moreover, the provided decision-making structure did not necessarily correspond to the natural order of the students' behavior when making a decision. Grace (2009) adapted the same decision-making framework and utilized it for group discussion on the issue of biological conservation. Three key roles were identified in the high-quality groups: (1) promoters of reflection who asked thought-provoking questions, (2) contributors of science content knowledge, and (3) information vigilantes who were able to use approachable information to clarify the pros and cons of the specific options (Grace, 2009, p. 562).

The other group of studies (Grace et al., 2015; Lee & Grace, 2012) investigated how the exposure of different cultures or contexts influenced students' decision making. Lee and Grace (2012) compared the decisions regarding the issue of avian flu made by Chinese students in Hong Kong and Guangzhou. Their findings showed that the students from different cultural settings held distinctive reasoning perspectives on evidence and selected diverse decision-making criteria. Since the students' selections of criteria were closely related to their values, the researchers suggested that the formation of criteria was implicitly and indirectly influenced by contextual factors. The second study explored how the exchange of views among students from different international locations: England, Germany, Hong Kong, and Sweden, impacted on their perspectives on the issue of whale hunting (Grace et al., 2015). The findings showed similarities as well as differences existing in the perspectives of students from different countries. This again manifested that culture may have an indirect impact on students' socioscientific reasoning and decision making (Grace et al., 2015). The students' positive feedback about exchanging video presentations among students from different cultural backgrounds entailed a promising pedagogical implication for broadening students' viewpoints.

Evidence-based reasoning, that is, how students search for and use evidence to reason, justify, and support their arguments, was the second focal point assessed during phase 1 (Dawson & Venville, 2010; Evagorou, Jimenez-Aleixandre, & Osborne, 2012; Khishfe, 2012). Evagorou et al. (2012) adopted an online argument construction tool (argue-WISE) to support students' data collection when making a decision on an environmental issue. The research team examined how the students were (or not) able to use the evidence from the learning environment to back their justifications. The results showed that the students were inclined to select evidence based on how they perceived the issue and to use the evidence in line with their decisions, while disregarding the evidence opposed to their views. Khishfe (2012) investigated how additional instruction on the NOS influenced the students' understandings of NOS and decision making in the context of genetic engineering. Khishfe found that NOS instruction significantly improved the students' understandings of NOS, but this did not seem to influence their decisions. Nevertheless, it should be noted that the groups which received NOS instruction considered and used more NOS-related factors when making a decision.

The other two interventional studies were conducted in socioscientific decision-making contexts; however, they did not directly delve into students' socioscientific decision-making performance. Dawson and Venville (2010) conducted a case study exploring the strategies that the teacher used to promote argumentation on the topic of genetics. Rather than looking at the students' decision-making or argumentation skills, the study identified four factors that promoted student argumentation: the role of the teacher in facilitating whole classroom discussion, the use of the writing frames, the context of the socioscientific issue, and the role of the students. Nicolaidou, Kyza, Terzian, Hadjichambis, and Kafouris (2011) were concerned about the issue of evidence credibility in evidence-based reasoning. They proposed the Bcredibility assessment framework^ and designed Web-based instructional materials to promote students' ability to evaluate evidence. This study demonstrated that the intervention helped improve the students' conceptual understanding of biotechnology-related concepts and the ability to evaluate the credibility of the evidence.

Phase 2 and Phase 3 Instructional Interventions

Various instructional interventions were developed to support students' use of appropriate decision-making strategies, such as introducing the optimization strategy (Nicolaou, Korfiatis, Evagorou, & Constantinou, 2009; Papadouris, 2012), training students in the use of different strategies, and using additional meta-cognitive approaches (Gresch & Bögeholz, 2013; Gresch et al., 2013).

Nicolaou et al. (2009) and Papadouris (2012) proposed using an optimization strategy as a simplification for better teaching of decision making. The optimization strategy includes four steps: (1) constructing a multi-attribute table to present connections between options and criteria, (2) converting raw data into a single matrix for holistic comparison, (3) assigning scores to the options for each of the criteria according to their importance, and (4) summing the total scores across various criteria for indicating the optimum solution. Nicolaou et al. (2009) piloted the optimization strategy with students and used an open-ended written test to evaluate their improvements in decision making. The results showed that the intervention was promising in terms of enhancing the students' decision-making skills: comprehending the context of a problem, developing evaluation criteria with proper evidence, distinguishing the relative importance of each criterion, comparing each available choice, and providing a thorough explanation of the decision taken. In the following study, Papadouris (2012) developed a more complete set of Web-based teaching and learning materials on the topic of energy for elaborating the optimization strategy. He implemented the instructional materials and used written open-ended tasks and semi-structured interviews to examine the effectiveness of the intervention. Significant improvements in the students' responses from the pre- to the post-tasks indicated that (1) students would not spontaneously develop the ability to reason and make well-informed socioscientific decisions through conventional science teaching and (2) it is possible to use a designed learning environment with explicit teaching treatment to support students' effective processing of data in socioscientific situations.

Böttcher and Meisert (2013) compared how two different instructional interventions (direct and indirect) influenced students' ability to use decision-making strategies. Two groups (EG1 and EG2) received the same instruction during the information searching stage. During the second stage, EG1 was taught a particular decision-making strategy and was required to apply this given strategy to a complex socioscientific context about genetically modified food. EG2 constructed their individual decision-making strategy and compared, discussed, and critiqued these individually developed strategies in small groups. Each EG2 sub-group came up with an eventual modification strategy. An in-depth analysis of the students' worksheets and group discussions revealed that direct instruction might result in a limited understanding of the decision-making process. The students evaluated the given strategy negatively or provided incoherent reasons for their positive comments. Some EG1 students even rejected the final decision made using the strategy because this was contrary to their personal views. On the other hand, the EG2 students were able to construct sophisticated decision-making strategies including compensatory trade-offs. The study suggested that, for learners, it is critical to understand the underlying reasons for using a particular decision-making strategy when making a decision. Indirect instruction approaches can be an achievable way to support students' development of valid decision-making strategies. However, a sufficient amount of time for reflection should be included when adopting a direct instructional approach.

Gresch and his research team (Gresch & Bögeholz, 2013; Gresch et al., 2013) contended that selecting a suitable decision-making strategy involves meta-cognition. In their two studies, two training groups received a session introducing three commonly used decision-making strategies. One of the training groups had to conduct a task analysis in which the group explicitly reflected on why the decision-making strategy was selected to fit the socioscientific context. The findings showed that the training session significantly improved the students' abilities to include both positive and negative aspects when weighting criteria and choosing/rejecting an option. However, conducting a task analysis as a meta-cognitive strategy did not seem to further enhance the students' decision making. The authors speculated that more time is needed for students to effectively use the newly acquired meta-cognitive strategy. Under the same research design, Gresch and Bögeholz (2013) further looked into how the students might be able to use and transfer meta-cognition skills to new tasks. The analysis revealed that about three quarters of the students were able to provide reflective explanations to illustrate their choice of the strategy. This implied that Belaborate meta-decision considerations^ (p. 749) were crucial in reaching thoughtful decisions.

Discussion

This section is intended to extend the knowledge from the analysis and to provide insights into the instructional design of socioscientific decision making. The following discussion is presented based on the three phases of the proposed socioscientific decision-making framework.

Instructional Insights for Phase 1: Formulate the Decision-Making Space

According to Acar, Turkmen, and Roychoudhury (2010), socioscientific decision making involves the process of identifying alternatives, collecting, analyzing, and weighing information pertaining to the alternatives and examining the pros and cons of the alternatives, before making a decision. Informal reasoning plays a crucial role in the aforementioned process. Our review of the literature on socioscientific decision making showed that, in addition to informal reasoning, evidence-based reasoning and social interactions were two research themes emphasized in this domain.

Instructional Design for Informal Reasoning and Evidence-Based Reasoning

The review indicated that two cognitive conditions, scientific knowledge and views on the nature of science, did not have an inevitably consequential or direct impact on students' informal reasoning. However, the improvement in scientific knowledge could lead to better evidence-based reasoning, such as enhancement of the quality of justification or the quality of reasoning. The more sophisticated the views on the nature of science, the more critical and the better the quality of their reasoning. For students, scientific knowledge was not necessarily the priority when making socioscientific decisions. In addition, despite the fact that students have sufficient knowledge, they might not be able to select relevant conceptual knowledge and connect/apply it in the socioscientific settings (Jho et al., 2014). That is to say, in addition to gaining conceptual knowledge, familiarizing students with relevant scientific knowledge involved in the socioscientific scenario and supporting them explicitly in making connections between the knowledge and socioscientific issues are both worthy of attention.

Socioscientific argumentation can be a useful pedagogy for linking scientific knowledge and socioscientific issues. It provides teachers and students with a platform for practicing and assessing evidence-based reasoning because argumentation requires using pertinent knowledge to make and justify claims and conclusions (Zohar & Nemet, 2002). Two factors, epistemological beliefs and evidence credibility, are interrelated in students' use of scientific knowledge. An individual's understanding of the epistemology of science will affect his/her interpretation of scientific knowledge (Sadler, 2004). Different interpretations will then influence how one perceives the strength of the justifications and whether or not to take the knowledge as one's priority. Similarly, the ability to assess evidence credibility affects how the scientific knowledge is used. Specifically, if one ignores evidence credibility or treats all evidence as equally strong, one may not be able to use the evidence appropriately as powerful support for the argument/counterargument.

Embedding a socioscientific decision-making framework in group discussions is regarded as a fruitful instructional design for enhancing students' informal reasoning. The framework can serve as guidance to keep group members on track and engaged in relevant information during discussion. As students have different merits, they can contribute to group discussions in different ways and benefit from each other. Previous research has identified the characteristics of high-quality discussions (Grace, 2009; Ratcliffe, 1997), but relatively little research analyzed how group members discuss and negotiate a collective decision. To improve not only individual socioscientific decision making but also quality and effective group decisions, it is suggested that future studies investigate relevant issues regarding socioscientific decision making at a collective level.

Exploring Other Cognitive Conditions

It appears that students' cognitive conditions other than scientific knowledge and epistemological views are rarely explored. Previous research has suggested that effective instructional interventions needed to encourage making personal connections to the issues discussed (Patronis, Potari, & Spiliotopoulou, 1999). It is speculated that students' personal relevance to or interest in a particular socioscientific context may play a role in their socioscientific decision-making performances. Future studies might probe into the effect of the factor of students' interest in socioscientific decision making and provide insights into the issue of how to select a suitable issue or context for enhancing socioscientific decision making.

Broadening Perspectives in Socioscientific Decision Making

Another facet of the first phase of decision making concerns the breadth of perspective students draw upon when making decisions in socioscientific issues, that is, in the interdisciplinary thinking or reasoning mode. The review of the studies showed that students' usage of reasoning modes might depend on the nature of the socioscientific issues. Also, the students who have more extended and richer cognitive structures are more oriented towards utilizing multiple reasoning modes. One application of the results is that the instructional design needs not only to deepen students' conceptual knowledge but also to broaden their knowledge of the context and to provide support for making links between these two fields of knowledge in regard to the socioscientific issue. As culture may implicitly shape one's value and indirectly influence one's perspective on the socioscientific issues, a group of researchers used group discussions and/or cross-context presentations to confront students with various perspectives. They concluded that students generally valued and learned from the sharing of perspectives with their counterparts around the world. More importantly, the cross-contextual exchange of perspectives was found to have an impact on students' multidisciplinary reasoning (Evagorou et al., 2012; Grace et al., 2015; Lee & Grace, 2012). Based on the findings, we suggest using idea-exchange or perspective-sharing activities in different contexts or cultural backgrounds, so that students can be stimulated by different ideas, reflect on their own reasoning, and broaden their perspectives.

Awareness of Personal Values

Researchers have suggested that students' personal values, in fact, play a significant role in formal reasoning. The studies by Jimenez-Aleixandre (2002) and Bell and Lederman (2003) showed that, regardless of whether they had high or low levels of conceptual understandings and epistemological views, students tended to use personal values to guide their socioscientific decision making. Therefore, Bdifferences in student reasoning modes or information preferences may reflect their knowledge structure and epistemological beliefs about what kinds of information are important in making decisions^ (Liu et al., 2011, p. 513). Kolsto (2006) further argued that, when using scientific knowledge in evaluations and decision making, it was the values that students held which decided what kind of knowledge was relevant, rather than whether the knowledge was, in fact, relevant to a particular argument. These researchers pointed out the importance of value-based reasoning in socioscientific issues. However, little research has been conducted to investigate students' value-based reasoning regarding socioscientific issues. It should be noted that the purpose of conducting research about value-based reasoning is not to examine how people use it; rather, it is about whether students are aware of their value-based reasoning and to what extent it is used (Acar et al., 2010).

Instructional Insights for Phase 2: Posit a Decision-Making Strategy

Whether and how decision-making strategies are used to make final decisions is one distinct feature of the studies focused on socioscientific decision making. Researchers have argued that for complex decision-making situations, such as sustainable development or nuclear power, intuitional decisions are likely to lead to disastrous consequences. Thus, it is pivotal to improve students' decision-making behavior regarding rational considerations (Gresch et al., 2013). Previous research has identified three models of decision-making behavior: non-compensatory (the elimination-by-aspects model), compensatory (the weighted-additive-value model), and mixed. They were introduced to support students in improving their decision-making processes. Two types of interventions were suggested in the review: (1) introduce students with three different decision-making strategies and guide them to select an appropriate one for a specific situation and (2) introduce simply one optimum decision-making strategy and train students to use it appropriately. Both of the interventions proved to be effective in terms of improving students' decision making. The students' abilities to effectively process relevant data and to weight criteria were improved. It should be noted that regardless of the intervention type, if the students did not meaningfully understand the strategy being used, they might reject the final decision because it was in conflict with their intuitions. Therefore, when designing learning environments for enhancing students' use of decision-making strategies, it is critical to integrate activities that offer opportunities for students to really understand, appreciate, and reflect on the strategy itself and why it is useful for decision making.

Instructional Insights for Phase 3: Review and Reflect on the Decision-Making Process

Students' meta-cognition in socioscientific decision making is generally discussed in the reviewed studies. However, the use of meta-cognitive guidance in the instructional design appeared to be limited in the review of the literature. To improve students' socioscientific decision making, we suggest designing activities to promote reflection or integrating meta-cognitive guidance in several key phases/steps.

Previous research has shown that students found it difficult to weight criteria. They often prioritized the criteria implicitly or simply gave them equal weight. Since socioscientific issues involve multiple dimensions, choosing one aspect over another normally cause conflicts. Therefore, having students explicitly prioritize the criteria and explain the reasons behind their choices might be a useful instructional approach. For instructional design, therefore, one can embed meta-cognitive prompts in phase 1 guiding students to establish a hierarchy for the criteria and to compromise on various dimensions. As individual perspectives and reasoning are rather restricted, having students reflect on their own reasoning and its underpinnings could be a beneficial way to help widen their perspectives in negotiating different alternatives. One potential instructional design is to expose students to contrasting and divergent perspectives. Several relevant designed activities such as grouping/pairing students with divergent views and using group presentations and discussions in the same class or among students with different cultural backgrounds were found to be potentially fruitful for stimulating students' reflections.

Meta-cognition is also critical in phase 2. Selecting a suitable decision-making strategy involves not only understanding the different decision-making strategies but also examining the features of the problem, the conditions of the decision, and the decision maker's own preferences (Beach, 1990). The reviewed studies highlighted the importance of reflecting on the use/selection of decision-making strategies, that is, the concept of meta-decision (Gresch & Bögeholz, 2013) or meta-strategic awareness (Papadouris, 2012). As mentioned in the previous section, they also provided useful ideas about how to design learning activities for supporting students' selection of and reflection on decision-making strategies (Böttcher & Meisert, 2013; Gresch & Bögeholz, 2013; Gresch et al., 2013; Papadouris, 2012).

Conclusions

Grace (2009) stated that Bthe quality of the decision-making process is more important than the quality of the decision itself^ (p. 565). From the perspective of the decision-making framework proposed in this review, we think it is sufficient to say a high-quality decision-making process can lead to a high-quality decision. This review provides a holistic framework which can help to analyze and conceptualize the research findings of socioscientific decision making in a more structured manner. Suggestions about the instructional design regarding each phase of the decision-making process are also presented. As the studies reviewed were conducted across diverse levels, a more careful instructional design tailored to different grade levels needs further research. It is acknowledged that using multiple types of interventions for multiple decision-making phases at the same time is not feasible because students may find it overwhelming. Therefore, future research may look into the ways to design a socioscientific decision-making curriculum so that students can continue their development of relevant competences in a more systematic manner.

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